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THE EFFECT OF LOCAL BETA IRRADIATION FROM AN EXTERNAL SOURCE UPON
THE GROWTH OF THE BONES AND SOME OTHER TISSUES OF RATS

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ABSTRACT

One-day-old rats were subjected to one-half (anterior or posterior) body irradiation by the beta rays of P^{32}. The skin exposure on the body was about 1,700 to 2,000 rep. The skin exposure on the tail, hands, feet, forearm, and leg was somewhat less than twice this. The animals were sacrificed at 200 days of age. No cutaneous tumors occurred. The irradiated animals weighed 5 to 10 per cent less than the controls. Males and females reacted alike. Changes were observed only in the part directly irradiated. The "anterior" animals had significantly smaller ears, skulls, and forelimbs; the "posterior" animals, tails, hindlimbs, and testes. Skeletal measurements are given. No effect was observed on the stomach, kidneys, liver, or heart.

* * * * *

The technics of external irradiation with beta rays have been presented by Raper, Zirkle, and Barnes,[4] and the gross effects following total-body irradiation were reviewed by Raper.[3] In the case of the 1.7 Mev beta rays from P^{32}, 95 per cent absorption occurs in 2.9 mm of soft tissue, and consequently their effects are limited to the skin in animals the size of rats, or larger. Such effects include epilation, ulceration, and tumor induction (Henshaw, Snider, and Riley[2]).

In the case of the mouse, however, penetration beyond the skin is appreciable, and Snider[5] found damage, upon histological examination, to one side of the spleen, one side of the testis, and in the marrow of the bones of the feet. It was obvious that baby rats would also show damage to the deep tissues.

Stapleton (unpublished experiments) compared the acute lethal effects of total and partial body exposure to P^{32} beta rays in the one-day old rat. For partial body exposure, the anterior or posterior half of the animal was employed. We have raised the survivors from some of these experiments, and have examined the relative growth of a number of organs, especially the bones. As might be anticipated, the parts irradiated show definite inhibitions of growth. The degree of inhibition exhibited by an organ correlated fairly well with its depth below the surface at the time of irradiation. The effects were local; inhibition of growth of the posterior half of the animal was without gross effect upon the anterior.

METHODS

Sprague-Dawley rats, less than 18 hours old, were employed. The rat was placed in a lucite cup which shielded either the anterior or posterior half of the body, and left the other half quite exposed. The cup was placed at the center of a box ($2\frac{1}{2}$ x $2\frac{1}{2}$ x $2\frac{1}{2}$ inches) lined with P^{32} plaques. The exposed part of the body therefore received radiation from all sides.

For purposes of calculation, the exposure chamber may be considered as a sphere, and the intensity of the radiation upon a point at the center will be the result of a 4π solid angle. A point on the surface of

a rat would receive radiation from a 2π solid angle because the body itself acts as a shield. In the case of the appendages, however, whose diameter is of the order of 2 mm, the shielding is much reduced and the exposure correspondingly increased. All animals received about 1,700 to 2,000 rep to the body, a dose representing the L.D.-50 per cent for animals whose total body was exposed. This dose was based on the reading of the pencil chamber, described by Raper, et al.,[4] placed at the center of the exposure box and considered to receive radiation from a 4π solid angle.

Although the body proper is sufficiently thick to prevent radiation from crossing it, in the case of the foot, leg, or tail, which have diameters of about 2 mm, this is certainly not the case. The result is that the skin of these members is subjected to higher exposure than on the body, and that the deep tissues also are seriously affected. Now, if there were no shielding, the geometry would be 4π; where shielding on one side is complete, it is 2π. The skin of the appendages, therefore, will receive something less than twice that of the body.

The exposure of the deep tissues of the appendages can be approximated in a rough sort of way. The average external diameter of the tail is about 1.5 mm, of the vertebrae within it 1 mm. In the case of the foot, the forearm, or leg, these may be considered as cylinders of about 2.5 mm diameter containing a centrally placed bone of half that diameter. Since the half-value layer for the beta rays of P^{32} is about 0.8 mm, the bone within all of these appendages will receive approximately the 2π dose.

The weaned rats were kept as groups of 10 to 15 in large metal cages, fed Purina dog checkers and water ad libitum, and were weighed every fortnight. At the conclusion of the experiment, they were anesthetized with ether and the neck vessels were slit to drain the body of as much blood as possible. After measuring the ears, feet, and tail, the body was skinned and the viscera removed, kept moist and weighed as soon as possible. The carcass was trimmed and then stored in 75 per cent alcohol. The bones were prepared by boiling the carcass (wrapped in cheesecloth) in 2 per cent Gold Dust soap powder for about one and one-half hours, after which the individual bones were readily cleaned by a little brushing, followed by washing in water for an hour or two and drying at room temperature.

The following linear measurements were made on the body and the prepared specimens; they represent the shortest distance between the two points mentioned and do not follow the convexity or concavity of the part except in one specified case.

Ear — from the notch at the base to the tip.

Hand — flexed, from the radiocarpal joint to the tip of the longest finger.

Foot — flexed, from the heel to the tip of the longest digit.

Tail — from the anus to the tip.

Tail vertebrae — counted in the skinned alcohol-fixed preparation, starting from an arbitrarily selected point which omitted one or two of the relatively fixed caudal vertebrae at the base of the tail.

Skull length — from the tip of the nasal bone to the external occipital crest following the surface.

Skull width — the linear distance between the tips of the two malar processes of the maxilla.

Mandible length — from the head of the condyloid process to the base of the incisor.

Mandible ramus — from the head to the angle.

Scapula — from the inferior angle to the tip of the coracoid process.

Humerus — the longest dimension.

Radius — the longest dimension.

Ulna — the longest dimension.

Femur — the longest dimension.

Tibia — the longest dimension.

RESULTS

The data are based on two series of animals, one of males and one of females. In each there is a control group, and anterior and a posterior irradiated group. The animals were sacrificed at the age of approximately 7 months. No cutaneous tumors were observed. The weights of the animals are listed in Table 1. Although in some cases the standard deviations are large, the data are consistent throughout: half-body irradiation reduced the total-body weight of the adult animal by 5 to 10 per cent. The reduction was small, but definite, and was essentially the same whether the anterior or posterior half had been irradiated.

Table 1.*

Age in days	Males			Females		
	C	A	P	C	A	P
100	279 (6)	246 (6)	243 (11)	197 (8)	185 (7)	184 (15)
	53	22	36	14	13	20
200	335 (5)	313 (3)	317 (8)	239 (6)	212 (6)	205 (13)
	29	7	27	11	12	14

* The body weight in grams, with standard deviation below, is recorded for control C, anteriorly exposed A, and posteriorly exposed P animals. The bracketed figures indicate the number of animals per group.

The gross appearance of the animals indicated immediately which end had been irradiated. The "anterior" animals had smaller heads, much smaller ears, and smaller hands (see Figure 1). The "posterior" animals had much shorter tails and smaller feet. In each case, the entire anterior or posterior member, respectively, appeared smaller. The differences observed were the result of impaired development of both bone and muscle in such a way that the limb as a whole appeared well proportioned.

The bone measurements of interest have been tabulated in Table 2. We were surprised by the relatively small standard deviations. In general, the effects were the same in both males and females. The legs and skull were shortened about 10 per cent, the tail about 40 per cent. The decreased length of the tail was due to impaired growth in almost all cases, and not to necrosis followed by shedding. The length of the ear (pinna) and the weight of the testes were reduced by 50 per cent. The stomach, kidneys, liver, and heart showed no significant difference. Irradiation of one-half of the body, in terms of these measurements, was quite without effect upon the other half.

The bones not listed in Table 2 did not show any significant shortening due to irradiation. Their measurements were:

	Male	Female
Jaw width	1.5 ±.1 cm	1.4 ±.1 cm
Jaw length	2.8 ±.1 cm	2.6 ±.1 cm
Scapula	2.8 ±.2 cm	2.6 ±.1 cm
Innominate	4.5 ±.2 cm	4.2 ±.3 cm

DISCUSSION

The results require no discussion except, perhaps, in one respect. The action of the beta rays upon the deep tissues has been studied hitherto by means of internal sources. While the latter possess certain

unique advantages, their use for some purposes is complicated by the fact that the duration of exposure and locus of action are not readily controlled. Raper, et al.,[4] in their discussion of methods, calculated that considerable deep tissue irradiation should be achieved by external sources in, for example, the foot of a small animal like the mouse. The present experiments are a simple example of this fact in the suckling rat.

The exposure in r of x-rays to inhibit the growth of the foot or tail bones of the one-day-old rat is not known. Barr, et al.,[1] reported that in the 30-day-old rat about 1,000 r inhibits the proximal end of the tibia by 50 per cent, and 1,800 r by about 100 per cent. For orientation, these figures may be compared to our estimates for the one-day-old tail and foot in which there were, respectively, 50 and 20 per cent inhibitions at a dosage of approximately 1,800 rep of beta rays.

Table 2.*

Item	Males						Females					
	Control		Anterior		Posterior		Control		Anterior		Posterior	
Number	5		3		7		11		7		11	
Skull												
length	4.8	0.1	4.3	0.2	4.8	.17	4.6	.08	4.2	.2	4.5	.2
width	2.3	.1	2.1	.06	2.3	.13	2.2	.08	2.1	.07	2.2	.1
Ears	1.9	.1	0.8	.1	1.9	.17	1.9	.06	1.0	.45	1.6	.46
Tail	21.6	.05	19.9	.38	11.8	1.8	17.1	1.4	17.3	.6	9.9	5.1
Vertebrae	26−27	---	25−26	---	24−28	---	24−26	--	24−27	---	24−25	---
Testes	3.7	.2	3.6	---	1.8	.96	---	---	---	---	---	---
Humerus	2.9	2.1	2.8	0.0	3.0	.09	2.7	.08	.08	.09	2.6	.1
Ulna	3.3	.2	2.8	.1	3.2	.15	3.0	.08	2.7	.1	3.0	.1
Hand	2.1	.05	1.9	.06	2.2	.1	2.0	.1	1.7	.1	2.0	.25
Total	8.3	---	7.5	---	8.4	---	7.7	---	7.0	---	7.6	---
Femur	3.7	.18	3.8	.1	3.5	.1	3.5	.08	3.5	.1	3.1	.8
Tibia	4.1	.2	4.1	.1	3.9	.1	3.9	.1	3.7	0.0	3.4	.3
Foot	4.0	.1	4.1	.15	3.2	.05	3.8	.13	3.8	.15	2.9	.4
Total	11.8	---	12.0	---	10.6	---	11.2	---	11.0	---	9.4	---

*The skeletal measurements are given in cm. The number of tail vertebrae is specified. In the case of the "posterior" femals, the vertebrae count applies to seven; the other four had stumps. One female control had a count of 16. With respect to the testes, the weight of both is given in grams. In the case of paired bones, both the right and left were examined, but only one side is given in the table because the results checked exactly.

In Figure 1, the rat on the left received 2,000 rep to the anterior half of the body, the one on the right is an untreated control. Note the difference in appearance of the head, ears, and forelegs.
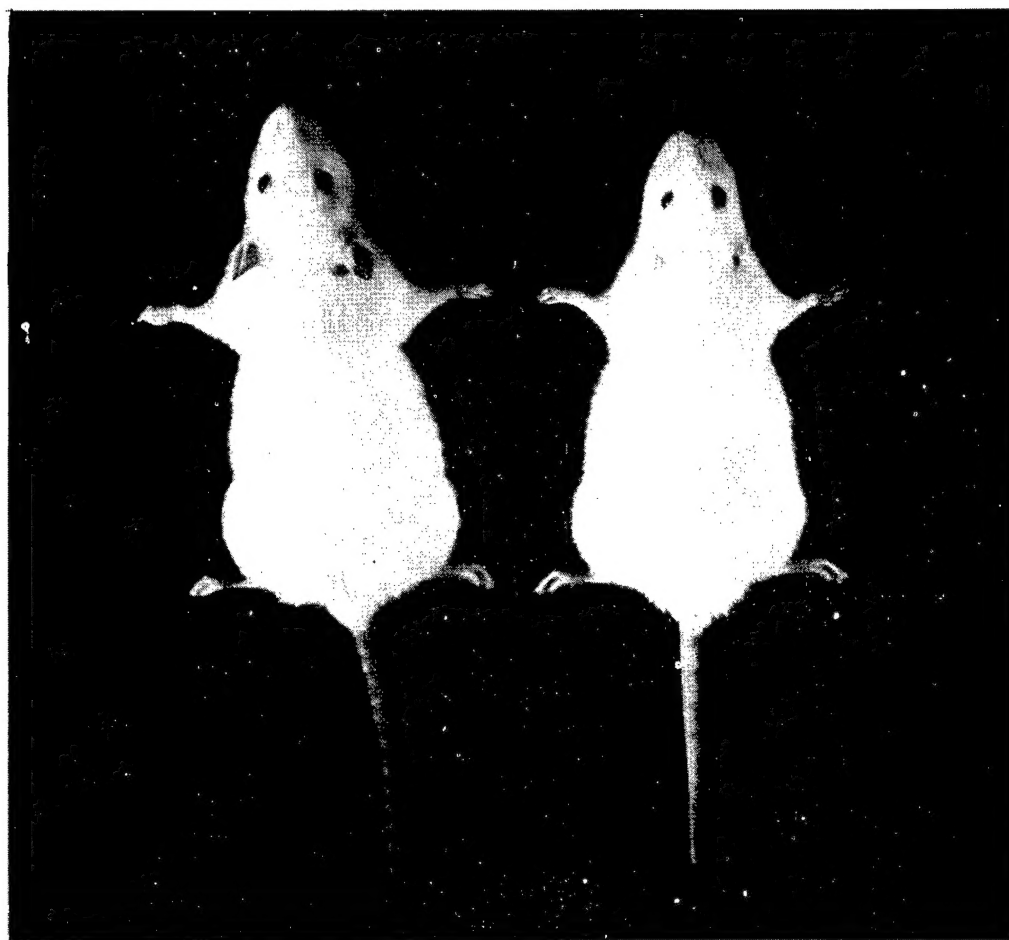

Figure 1.

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